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UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
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INFORMATION CIRCULAR

MINERAL INDUSTRIES SURVEY OF THE UNITED STATES

COLORADO
LAKE COUNTY

POSSIBILITIES OF MANGANESE PRODUCTION AT LEADVILLE, COLO.

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FOREWORD

In connection with the strategic minerals investigations now being conducted by the Bureau of Mines, consideration was given to Leadville, Colo., as a possible source of manganese that might be made available for use under circumstances of national emergency. It appeared, however, that because many of the mines were shut down and flooded the information desired could not be obtained directly by sampling. A study of evidence afforded by maps and production records, considered in connection with geological reports, promised a more satisfactory, if not the only possible, approach to the problem.

The Mineral Industries Survey Section of the Mining Division was accordingly directed to make the study desired, on behalf of the strategic minerals investigations. As the report contains information that is likely to be of considerable interest to many, it is here presented as an information circular of the mineral industries survey series.

CHAS. F. JACKSON,
Chief Engineer,
Mining Division.

POSSIBILITIES OF MANGANESE PRODUCTION AT LEADVILLE, COLO.[1]

By J. H. Hodges[2]

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7125."

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Summary and Conclusions

During the World War Leadville was an important producer of manganese and manganiferous ores for the steel industry. Normally, the market for these ores is limited to the requirements of the local steel mill at Pueblo for low-grade ores used in making basic pig iron containing 1 to 2 percent Mn and spiegeleisen containing 20 percent Mn, but during the war and a brief period of postwar readjustment, a good deal of 25- to 40-percent manganese ore was shipped to eastern steel-manufacturing centers.

Throughout the active life of the camp, manganiferous iron ore carrying a little silver and lead and sometimes as much as 35 percent Mn was shipped to lead smelters for flux. The total recorded production is 936,024 tons of metallurgical ore shipped to steel mills and 2,576,514 tons of fluxing ore, much of it of metallurgical grade.

Manganese is abundant in association with virtually all the extensive blanket replacement deposits from which the bulk of the camp's enormous output has been derived. It occurs generally as a casing or halo surrounding bodies of lead or zinc carbonates or sulfides. In the zone of oxidation, the iron and manganese minerals are quite thoroughly oxidized, while in the sulfide zone they are found in the form of manganosiderite. All shipments have been oxidized material, no use having been found for manganosiderite.

The local claim that reserves of 16- to 25-percent manganese ore exceed 2,000,000 tons may be accepted. How much of this is recoverable is problematic because of the physical condition of the mines.

Rehabilitation of the mines is contingent upon greatly improved markets for lead and zinc that would offer enough inducement to justify undertaking the costly and speculative venture of unwatering and reopening long-abandoned and doubtless badly caved workings in an area noted for heavy ground.

Complete drainage by pumping would cost close to a million dollars and would take 2 years. A proposed drainage tunnel, 38,000 feet in length including laterals, would drain the principal areas to a level below most productive horizons at a cost of 2 to 2-1/2 million dollars and would require a minimum of 2 to 3 years to complete.

Recent activity has shown that reserves of manganiferous iron ore containing 16 to 25 percent Mn exist above water or are accessible with a moderate amount of pumping and that this ore can be mined to yield a small profit at a net price, f.o.b. mine, of $6 to $7 a ton. Given an assured market at a slightly higher price, it is believed that 100 tons a day of this grade of ore would be produced. Failing general reopening of the mines due to other influences, it is doubtful whether manganese output could be raised much above this figure.

Attempts to find an economic method of concentrating the manganese to a product satisfactory for the manufacture of ferromanganese so far have been unsuccessful. Investigations are continuing at Bureau of Mines laboratories.

These ores doubtless would be amenable to leaching for production of electrolytic manganese. The metal would be considerably more costly than manganese in ferro at customary prices but might conceivably be cheaper than top wartime prices. To the lay mind it appears technically feasible to substitute metallic manganese for ferromanganese alloy in the open-hearth steel process. This is not generally conceded, but the possibility of such use as an emergency measure should be investigated.

Genesis and Mode of Occurrence of Iron-Manganese Ores in Leadville District

Emmons' first study of the Leadville district, undertaken shortly after the establishment of the Geological Survey in 1879, revealed the general geologic features that controlled mineral deposition. The better understanding thus obtained of ore occurrence in the district aided enormously in the search for ore bodies that hitherto had been more or less haphazard and often guided by erroneous conceptions. Subsequent observations - over a 45-year period, by Government geologists and engineers and geologists associated with operations of the various mines - of new evidence revealed as mine workings were extended led to a very thorough, complete, and authoritative analysis of the complex geology of the district, reported in Professional Paper 148 published by the Geological Survey in 1927.[3] The conclusions presented in this report regarding structural relationships and deposition of ore by replacement of wall rocks differ little in most essentials from the fundamental concepts advanced by Emmons in Monograph 12, published in 1886. However, with regard to the genesis of the ores, Emmons' original view, later modified, that they were deposited by hot meteoric waters at high pressure that derived their metallic content from porphyry masses was discarded. Conclusive evidence was revealed that the ores were of deep-seated origin, transported and deposited by magmatic waters rising along channels in the fractured and faulted sediments subsequent to the two periods of intrusive action that introduced the white and gray porphyries, respectively.

(a) Factors influencing distribution of minerals.[4]

The ore deposits are found over a vertical range of about 900 feet in a series of Paleozoic quartzites, limestones, and shales that were laid down on a pre-Cambrian complex of granite, schist, and gneiss to an aggregate thickness of about 1,500 feet. Although no longer found in Leadville there is evidence in the surrounding country that some 8,500 feet of late

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[3] Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and Ore Deposits of the Leadville Mining District, Colorado: Geol. Survey Prof. Paper 148, 1927, 368 pp.

[4] Work cited in footnote 3.

Carboniferous sediments once present have been removed by erosion. Thus, according to Loughlin,[5] the total thickness of the strata at the end of Cretaceous time ranged from 8,000 to 12,000 feet and intrusive sheets of porphyry of late Cretaceous or early Tertiary age increased the thickness by 2,500 feet or more.

Ore deposition occurred after the porphyry intrusions and following a period of folding and faulting that provided channels for metal-laden magmatic waters. It is believed to have taken place under a cover of 10,000 to 12,000 feet of rock. Rising aqueous solutions, impeded in their upward course by impervious porphyry sills and shale beds, spread out into the soluble limestones underneath these barriers to form the extensive replacement ore bodies from which the bulk of production has been derived.

The replacement bodies commonly occur at certain horizons or "contacts" controlled by the porphyry sills or shale beds that lie above or within the blue or white limestone. Deposition in fault and fissure veins likewise formed important bodies of ore, particularly in the eastern part of the district, but only the replacement or blanket deposits have been significantly productive of manganese and manganiferous ores.

An intrusion in the stock beneath Breece Hill distinctly later than the porphyry sills is believed to be closely related to ore deposition and to mark Breece Hill as the chief source from which mineralization proceeded. Extensive post-mineral faulting has taken place and in some instances movement along these faults has continued or been repeated at intervals until the present time.

The processes of ore deposition postulated in Professional Paper 148, insofar as they relate to the association of manganese with bodies of lead-zinc-silver ore in blanket deposits, may be summarized very briefly as follows: Magmatic waters escaping from the magma reservoir (presumably related to the Breece Hill stock) along channels provided by numerous faults and fissures were held back by impervious barriers of shale or porphyry and spread out into the soluble limestone beds underneath them, replacing the limestone with the minerals carried in solution. Manganosiderite evidently began to replace the limestone at a temperature too high for deposition of sulfides, but at a lower temperature the sulfides were more stable and replaced manganosiderite. The manganosiderite was transferred in solution to localities where it could again replace limestone around the margins of the sulfide ore bodies.

(b) Relation of iron-manganese bodies to deposits of lead and zinc carbonates and sulfides.

This theory of deposition explains the very general occurrence of iron-manganese minerals more or less completely encasing bodies of lead or zinc ores. In the zone of oxidation the manganosiderite has been altered to oxides of iron and manganese, forming the extensive bodies of manganese and manganiferous ores from which shipments to steel mills and smelters have been drawn. Manganosiderite so closely resembles limestone in appearance that it was not recognized for many years. When finally identified and its relation to sulfide bodies understood, its presence was considered to be indicative of an ore body near by.

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[5] Work cited in footnote 3.

(c) Influence of Tucson Maid fault

The deposition of iron-manganese minerals in relatively high concentration surrounding bodies of lead-zinc ores is particularly apparent in the Iron Hill, Carbonate Hill, Fryer Hill and Downtown areas. Intense mineralization there appears to emanate from the Tucson Maid fault zone, which is thought to have provided the chief trunk channels for access of the mineralizing solutions to this western region relatively remote from the center of mineralization.

Silica in the mineralizing solutions reacted in much the same way as the iron-manganese carbonates but tended to react at greater distances from the trunk channels. Loughlin[6] noted casings of jasperoid rather than manganosiderite surrounding the sulfide bodies at points distant from the Tucson Maid fault zone in the Iron Hill-Carbonate Hill-Downtown sections, and concluded that manganese ores would tend to become lower grade and more siliceous as distance from the fault increased.

Production of Manganese and Manganiferous Ores

The shipment of iron-manganese fluxing ores from Leadville to western smelters was first noted in Mineral Resources of the United States for 1885, but no record of actual shipments was made until 1889. From 1886 to 1888, inclusive, the tonnage of fluxing ore shipped was estimated by the Geological Survey to have averaged 60,000 tons per year. Shipments of metallurgical ore first were noted in 1889.

(a) Total recorded production to date

Total estimated and recorded shipments of metallurgical and fluxing ores from 1886 to 1939 are shown in the following table.

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[6] Work cited in footnote 3.

Manganiferous iron ore produced in Leadville, 1886 to 1939

Year	Metallurgical Ore				Fluxing Ore	
	Grade, percent Mn	Quantity, long tons natural	Net value, f.o.b. Leadville		Grade, per-cent Mn	Quantity, long tons natural
			Total	Average		
1886-88	-	-	-	-	-	180,000
1889	-	2,075	-	-	-	64,987
1890	-	6,397	$25,588	$4.00	-	51,840
1891	-	964	7,230	7.50	-	79,511
1892	25-38	2,942	14,710	5.00	-	62,309
1893	30	5,766	23,064	4.00	-	55,962
1894	25	7,022	26,822	3.82	-	31,687
1895	28	13,464	40,661	3.02	-	54,163
1896	22-35	9,072	38,069	4.20	-	138,079
1897	27-31	16,519	39,565	2.40	-	149,502
1898	18-33	18,843	61,785	3.28	-	99,651
1899	16-43	29,355	86,697	2.95	-	79,855
1900	18-45	43,303	205,256	4.74	-	183,509
1901	16-30	62,385	248,084	3.98	-	228,187
1902	18-32	13,275	52,371	3.95	-	194,132
1903	-	14,856	55,710	3.75	-	179,205
1904	15-32	17,074	54,104	3.17	-	105,278
1905	14-41	45,837	110,497	2.41	-	81,738
1906	26-36	32,400	97,600	3.01	-	no record
1907	20-25	41,694	98,311	2.36	8-26	31,544
1908	22-26	15,973	39,463	2.47	6-22	35,581
1909	-	12,905	29,632	2.30	-	52,119
1910	-	-	-	-	5-26	55,770
1911	-	-	-	-	4-40	41,753
1912	-	-	-	-	6-24	48,618
1913	-	-	-	-	2-37	49,753
1914	21	2,100	4,956	2.36	5-37	37,781
1915	20-35	15,956	41,527	2.60	5-30	14,965
1916	24-46	90,600	296,262	3.27	5-35	16,263
1917	19-32	104,115	267,284	2.57	5-37	20,600
1918	16-40	103,855	723,179	6.96	5-35	24,931
1919	26-39	22,221	359,927	16.20	5-35	29,769
1920	19-40	14,629	152,170	10.40	3-22	34,670
1921	20-41	1,414	18,527	13.10	3-25	10,819
1922	-	-	-	-	4-18	13,951
1923	18-38	20,626	109,407	5.30	2-27	10,376
1924	13-38	25,270	138,849	5.49	13	4,484
1925	17-38	5,893	24,296	4.10	5-28	11,448
1926	18-22	2,925	12,700	4.34	12-22	6,676
1927	19-35	26,828	126,938	4.73	-	-
1928	21-23	18,516	99,242	5.36	11	48
1929	21	17,770	92,801	5.22	-	-
1930	20-23	19,730	109,796	5.56	-	-
1931	24	3,885	21,880	5.94	-	-
1932-35			no shipments			
1936	17	8,923	40,154	4.50	-	-
1937	18	11,326	58,082	5.13	-	-
1938			no shipments			
1939	17	7,516	50,701	6.75	-	-
Total..	-	936,024	$4,103,952	4.39	-	2,576,514

(b) Influence of price and fluctuating requirements of smelters and steel plants on disposition of manganiferous ores

In considering the manganiferous ores of Leadville no sharp distinction can be made between metallurgical ores and fluxing ores. The two classes overlap widely, and it appears from the record that the destination of a given shipment was likely to be determined by the relative needs at that particular time of the smelters and steel plants within the shipping radius of the mines.

In general, ore containing over 20 percent manganese and low in silver usually has brought a better price from the steel mills and with less than 20 percent manganese, high iron, and 5 ounces or more silver, it has been worth more as flux. However, shipments to smelters have run as high as 40 percent and to steel mills as low as 13 percent manganese.

(c) Character of ores.

Combined iron and manganese in these ores, mostly in the form of oxides, ranges from 40 to 55 percent and silica from 6 to 20 percent or more; they may carry from a fraction of an ounce to as much as 10 ounces of silver per ton. Five ounces or more is likely to tip the scales in favor of selling to the smelter. Phosphorus is low, generally less than 0.10 percent, but there may be enough zinc to give trouble in the blast furnace.

(d) Smelter schedules.

Schedules in effect in 1915 for metallurgical and fluxing ores applied to a fairly typical 20-percent Mn ore illustrate how an ore of this grade under the conditions then prevailing might be sold for either use, and slight variations in its components might determine the more profitable market.

The 1915 schedule of the Colorado Fuel & Iron Co. for metallurgical ore was as follows:

$2.75 per ton for 25% Mn, 25% Fe, 8% SiO_2, 12% H_2O

Premiums - $0.08 per unit of Mn over 25 dry
.04 per unit of Fe over 25 dry
Penalties - .08 per unit of Mn under 25 dry
.04 per unit of Fe under 25 dry
.03 per unit of SiO_2 over 8 dry
.03 per unit of H_2O over 12

The **American Smelting & Refining** Co. schedule for fluxing ore was as follows:

No treatment charge or penalties.

Pay - 95% of the Ag at New York quotations
$0.15 per unit for excess over 40% of combined Fe and Mn less SiO_2.

Assume an ore of the following analysis:

3.75 oz. Ag, 20% Mn, 30% Fe, 6% SiO_2, 10% H_2O; silver at $0.50 an ounce (the average price in 1915).

Applying the Colorado Fuel & Iron schedule, the net value of this ore would be $2.37 per ton, as follows:

Flat rate per ton			$2.75
Premium	- Fe, 5% at $0.04		+ .20
			2.95
Penalties	- Mn, 5% at $0.08	$0.40	
	H_2O, 6% at $0.03	.18	- .58
Net value per ton			2.37

Under the American Smelting & Refining schedule for flux the ore would net $2.38 per ton as follows:

Silver	- 3.75 x $0.95 at $0.50	$1.78
Fe - Mn excess = 20 (Mn) + 30 (Fe) - 6 (SiO_2) - 40 = 4 at $0.15		.60
Net value per ton		2.38

Normally the market for these ores is purely local, and prices offered vary with the needs of local smelters and the steel plant at Pueblo. Production likewise is limited by the combined requirements of these two outlets. The average net value at the mines of all recorded shipments of metallurgical ore from Leadville mines from 1890 to 1939 was $4.39 per ton. The lowest annual average was $2.30 in 1909 and the highest $16.20 in 1919, the latter reflecting the enlarged demand for domestic manganese ores during and immediately after the World War period.

(e) Principal producing mines

The following mines comprise the principal groups from which manganese or manganiferous ores have been produced.

Iron Hill-Rock Hill group

Benton
Bullseye
Crescent
Cord
Great O'Sullivan
Gray Eagle
Nisi Prius
Tucson
White Cap

Carbonate Hill group

Agassiz
Aetna
Big Chief
Castle View
Carbonate
Catalpa
Evelyn
Emmett
Greenback
Henrietta
Hegeman
Haytrosser
Modoc
Mahala
Maid of Erin
Orion
Pendery
Porter
Star Consolidated
Star of the West
Seneca
Vanderbilt
Wolftone
William Wallace
Yankee Doodle

Downtown group

A. V.
Alice Placer
Bohn
Coronado
Home Extension
Penrose
Star
Sixth Street

Fryer Hill group

All Right
A. M.
Amie
Buckeye
Blonger
Bangkok
Chrysolite
Climax
Cady
Capitol Northern
Cora Belle
Dunkin
Denver City
Fairview
Forepaugh
Gambetta
Hope
Hibschle
Hazzard
Harvard No. 1
Jason
Little Chief
Little Sliver
Matchless
May Queen
McCormick
Pandora
Quadrilateral
Result
Robert E. Lee
Tip Top
Wolcott

All these mines are in the western half of the district, where most of the enormous replacement bodies of lead and zinc carbonates and sulfides are found at several horizons or "contacts" in the blue and white limestones. The following mines in the eastern half of the district likewise have reported shipments of manganese or manganiferous ores, but their total output is relatively unimportant.

Mine	Location
Del Monte	Yankee Hill
Highland Chief	Breece Hill
Luema	Upper Evans Gulch
Mammoth	Yankee Hill
Penn No. 1	Breece Hill

Reserves

The extensive replacement ore bodies in the Leadville district are so irregular in shape, size, and distribution that they do not lend themselves readily to systematic development. Although it doubtless would have been possible in the more intensively mineralized areas to have blocked out large tonnages of ore in advance of mining, it appears that this seldom was done to any great extent. For many years ore was so plentiful that there was little inducement to expend time and energy or tie up capital in blocking out reserves that would serve no useful purpose as long as there were plenty of working faces from which to mine all the ore that could be marketed or that the equipment could handle. Discovery kept well ahead of production, and the general practice seems to have been to proceed at once with the mining of an ore body from one or more points by means of open stopes, supported by cribs that sometimes reached phenomenal proportions, and to follow the ore in all directions to its irregular boundaries. By this method, low costs were achieved, and the ore bodies were so large that there was no shortage of ore until the mines approached exhaustion. Curtailment or suspension of operations at various times during the active life of the camp was due to unfavorable markets, coupled with the growing cost of handling large volumes of water at depth.

(a) No measurable reserves

The manganese and manganiferous ores were mined as required and justified by market conditions from areas adjacent to the old lead and zinc carbonate stopes. The abundance and wide distribution of these ores are attested by the large number of mines from which important shipments were recorded year after year, but the total output was relatively small in proportion to the total production of gold-silver-lead-zinc ores from the district. These facts, in conjunction with geologic evidence pointing to manganese as one of the major constituents of the mineralizing fluids, support the surmise that the ratio of manganiferous ore mined to the total output of the camp is considerably less than the volumetric ratio of manganiferous deposits to total mineral deposits in the district. Hence reserves of considerable proportions may be conjectured, but with mine workings now caved and inaccessible no engineering data in support of these conjectures are obtainable. Guesses by the conservative minded are likely to fall short of the truth, while those more optimistically inclined can easily convince themselves that vast quantities remain to be mined.

(b) Estimates of Umpleby, Furness, Dickerman, and others

Estimates of reserves based upon such first-hand observations and measurements as were possible at the times of their visits, supplemented by information from reliable local sources, were made by Umpleby[7] in 1917 and Furness[8] in 1927.

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[7] Umpleby, J. B., Mineral Resources of the United States, 1919, p. 94.
[8] Notes by J. W. Furness in Bureau of Mines files.

Umpleby reported reserves in 13 deposits examined totaling 700,000 tons of 5 to 35 percent grade with 800,000 tons additional in prospect. Since this estimate was made (in August 1917) approximately 500,000 tons have been shipped, much of it from deposits not included in his estimate, which would leave a prospective reserve exceeding 1,000,000 tons.

In 1927 furness estimated a total reserve in nine mines of 856,000 tons of 10- to 35-percent manganese ore. Since 1927, shipment of 87,466 tons has been reported, leaving approximately 770,000 tons to be mined.

The Committee on Industrial Preparedness of the American Institute of Mining and Metallurgical Engineers in its report of January 29, 1924, to the War Department estimated reserves in Colorado of 150,000 to 250,000 tons of ferro-grade ore (35+ percent Mn) and 1,500,000 to 2,500,000 tons of spiegel and basic pig grades (5 to 35 percent Mn). Manganese occurs in small quantities at a number of points in the State, but virtually all important reserves are in Leadville mines. This report was based upon information compiled from many sources.

Ezra Dickerman, who operated the Star Consolidated properties for many years and was one of the largest shippers of manganese ores, is quoted by Furness[9] to have estimated Leadville reserves at 4,000,000 tons of 30 percent ore at the close of 1918, of which only about 2,000,000 tons could be recovered owing to the condition of the mines. Since 1918 about 350,000 tons of manganese ore of all grades have been shipped.

Jesse F. McDonald was for many years in charge of operations for the Downtown Mines Co., which was formed about 1914 to consolidate holdings in the Downtown and lower Carbonate Hill area for the purpose of unwatering the mines of this section through the Penrose shaft. When unwatering was completed in 1916 shipments of manganese ore from these mines began and was continued until, as McDonald expressed it to the author, they were "cut off at the pockets" when the armistice was signed in November 1918. They were then shipping 1,500 to 1,800 tons a month to Pueblo, Chicago, and Pittsburgh. McDonald states that, given a market and the water out of the mines, they could take up where they left off. He believes Dickerman's estimate of 2,000,000 tons of recoverable ore to be conservative. Others familiar with the district, who were consulted, are in general agreement with this figure.

The foregoing statements relate to oxidized ores only and make no allowance for manganosiderite generally conceded to be present in its original state and in large quantity surrounding sulfide ore bodies below the limits of oxidation. They indicate with a considerable degree of authority reserves of around 1,000,000 tons of ore containing 5 to 35 percent manganese in a dozen of the more productive mines and the probability that another million tons may be found in the extensive areas exploited by the 79 producers listed above and many others not noted.

(c) Estimate derived from assumed relation between stoped areas and original volume of manganiferous ores.

In an effort to find substantiating evidence such old mine maps as were available in Leadville offices were studied with negative results. For the most part the maps are incomplete, and none of those examined show unmined ore or indicate the class of ore mined from the stopes mapped. The most complete and graphic picture of the size and distribution of stopes in the blanket orebodies is presented in plate 45 of Geological Survey Professional Paper 148, painstakingly compiled from mine maps during a period of active operation. Here, too, the picture is one of worked-out stopes, and doubtless the records of many old workings were lost or unavailable when this compilation was made.

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[9] Reference cited in footnote 8.

Maps and records available at this time provide no concrete evidence of reserves of any of the various classes of ore that the mines have produced in such abundance. Lacking any better method, it was thought that the recognized genetic relationship between the blanket deposits of silver-lead-zinc ores and the iron-manganese bodies, applied to the stoped areas shown on plate 45, might give some reasonable clue to the total original volume of manganiferous bodies from which some measure of the unmined portions could be gained.

The manganese occurs as a casing surrounding lead-zinc replacement deposits in the blue and white limestones. It is quite generally found in this relationship to ore bodies adjacent to the Tucson Maid fault zone, in the Iron-Rock Hill area, Carbonate Hill-Downtown area, and Freyer Hill area. It is found alongside and underneath the ore bodies but is less likely to occur in quantity above because the lead-zinc ore usually was deposited in contact with overlying impervious porphyry or shale. The manganese casing may be relatively thin but is likely to be of substantial thickness. It may become highly siliceous and finally give way to jasperoid at greater distances from the Tucson Maid fault.

There is little definite information regarding the dimensions of manganese ore bodies; hence, any general assumption is subject to a large percentage of error. Loughlin[10] states that such manganese stopes as he had an opportunity to examine were small and irregular compared with those of other ores. Umpleby[11] described a fairly homogeneous mass of ore 120 feet thick in the Fairview or All Right No. 1. Its areal extent had not been proved, but it had been opened for a length of 200 feet and a width of 75 feet, and at least three similar ore bodies had been found in that vicinity. Furness mentions thicknesses ranging from 8 to 75 feet. Many of the blanket orebodies were 50 to 60 feet thick, and at least one is described as 200 feet thick.[12]

The total areal extent of all replacement ore bodies in blue limestone shown on plate 45[13] in the Carbonate Hill-Downtown, Adelaide, Fryer Hill, and Iron-Rock Hill groups is approximately 8,900,000 sq. ft. If it is assumed that iron-manganese ore of varying thickness but equal areal extent underlies these bodies and that 1 ton of iron-manganese ore in place occupies 12 cubic feet, then the quantity originally contained in these deposits would be 740,000 tons per foot of thickness. If an average thickness of 10 feet is assumed the total would be 7,400,000 tons. Deducting recorded shipments of 3,500,000 tons leaves an indicated residue or reserve of 3,900,000 tons, of which a minor but indeterminate part would be manganosiderite of doubtful value, and part would be unrecoverable because of the physical condition of the mines.

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[10] Work cited in footnote 3, p. 222.
[11] Umpleby, J. B., Min. and Sci. Press, Nov. 24, 1917, p. 758.
[12] Work cited in footnote 3, p. 191.
[13] Work cited in footnote 3.

The only useful purpose of this calculation is to envisage the tonnage possibilities of the area for comparison with the manganese ore reserves claimed by the operators. Certain factors tend to place the calculation on the conservative side.

(1) Stopes mapped on plate 45 are as of 1922. Some older stopes doubtless are missing, and nearly 2,000,000 tons of ore have been mined since that date, extending the stope areas 10 to 15 percent.

(2) The average thickness of the iron-manganese casing surrounding zinc-lead bodies is generally stated to be 20 to 30 feet. Actual manganese stopes are reported ranging from 30 to 120 feet in height.

(3) Areas measured are horizontal projections whereas virtually all the orebodies parallel the bedding of the tilted sedimentaries at dips of 10° to 70°.

(4) Manganese is found alongside as well as underneath the old stopes. This halo is not considered in the calculation, except insofar as manganese stopes are included in those mapped.

The following tabulation of stoped areas in the blue limestone and equivalent tonnages indicates the relative intensity of mineralization in the various areas under consideration.

Aggregate Horizontal Areas of Stopes in the Blue Limestone in the Western Part of the Leadville District

	Area, sq. ft.	Tons per ft.	
Carbonate Hill-Downtown:			
Blue lime under white porphyry	2,965,760	247,147	
Blue lime under gray porphyry	1,043,200	86,933	334,080
Adelaide:	21,120	1,760	1,760
Fryer Hill-Poverty Flat:			
Blue lime under white porphyry	1,187,200	98,933	98,933
Iron-Rock Hill:			
Blue lime under white porphyry	2,023,680	168,640	
Blue lime under gray porphyry	1,654,400	137,866	306,506
	8,895,060		
Total (manganiferous ore in blue lime) per ft. thick			741,280

If average thickness 10 ft., total original tonnage	7,412,800
Total oxidized Fe-Mn ore shipped	3,512,538
Residue	3,900,262

In addition to the stopes included in the above calculation, those in the white limestone in the same areas total 748,800 square feet in horizontal section. Virtually all of these stopes are below the limits of oxidation, and the manganese associated with them may be assumed to be in large part unaltered manganosiderite.

The white limestone was more thoroughly explored and more productive in the Iron Hill area than anywhere else, and the association of manganosiderite with lead-zinc sulfide bodies was observed and studied by Philip Argall in the Tucson mine[14]. Samples at 10-foot intervals in a crosscut from a stope on the fifth level showed that the limestone had been completely replaced for 30 feet beyond the limits of the lead-zinc ore by manganosiderite containing 20 percent Mn and 21 percent Fe. Manganosiderite is stated by Loughlin[15] to occur in abundance in the Downtown, Fryer Hill, Carbonate Hill, and Iron Hill areas as well as in the Ibex mine on Breece Hill and other Leadville mines. An ore mass 750,000 square feet in horizontal section and 30 feet thick would contain approximately 1,875,000 tons.

(d) Loughlin's estimate of possible reserves of lead-zinc ores in inadequatel explored areas geologically favorable

Loughlin in his report[16] on the proposed deep drainage tunnel for the Leadville mining district cites various geologically favorable areas in which the white limestone has not been adequately explored and by analogy with the productivity of similar areas that have been exploited estimates a possible undiscovered reserve of 2,000,000 tons of sulfide ore. Further development in the white limestone likewise would expose bodies of manganosiderite that might aggregate several hundred thousand tons. It is logical to infer that total reserves of manganosiderite exceed 2,000,000 tons containing 14 to 20 percent Mn.

To summarize, it may be reasonably assumed that there are in the Leadville district 2,000,000 tons of oxidized manganese and manganiferous ores containing 10 to 35 percent Mn, and 2,000,000 tons of manganosiderite containing 14 to 20 percent Mn. Much of the oxide ore in caved areas adjacent to old caved stopes would be difficult or expensive to recover. No commercially feasible method has been found for utilizing manganosiderite.

Strategic Importance of Leadville Manganese

(a) Circumstances of use and supply

In order of importance, manganese ranks first on the list of minerals designated as strategic by the Army and Navy Munitions Board because it is essential to the manufacture of steel - most important of war materials - and because, even under the stimulus of war prices in 1918, domestic mines produced only 35 percent of the manganese consumed, in the form of ferromanganese and spiegeleisen, by the steel industry. In 1937 steel production rose to 50,000,000 tons that required approximately 325,000 tons of manganese metal in alloys in its manufacture. Over a million tons of ore of grades from which standard ferro and spiegel can be made are required to supply this quantity of manganese, and much more would be needed if the lower grades available from domestic mines were used. If this country should become involved in another war, it is estimated that 60,000,000 tons of steel per year and nearly 400,000 tons of manganese metal would be required.

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[14] Work cited in footnote 3, pp. 152-153.
[15] Work cited in footnote 3, p. 152.
[16] Loughlin, G. F., Report to Public Works Administration.

(b) Normal market for Leadville ores

Normally the market for Leadville manganese other than that used for fluxing is limited to the needs of the Colorado Fuel & Iron plant at Pueblo, part of which are supplied from New Mexico and other nearby sources. In the past this market has absorbed 10,000 to 60,000 tons a year of 13- to 40-percent ore. The lower grades are used to make manganiferous or basic pig for the basic open-hearth steel furnace, and the higher grades are converted to spiegeleisen or low-grade ferromanganese.

(c) Utilization of Leadville ores during the World War shortage

During the war years 1917 and 1918, Leadville produced over 100,000 tons a year of 20- to 40-percent manganese ore. In addition to supplying the local market, a large tonnage was shipped to manufacturers of ferromanganese in eastern steel centers (Chicago, Ill., Pittsburgh and Temple, Pa., and Birmingham, Ala.). Thus Leadville became one of the important sources from which high-cost supplies of relatively low grade were drawn to supplement reduced imports of high-grade manganese ore.

These lower-grade ores were mixed with high-grade foreign ores to make a 70-percent ferro to which the furnace men had to become accustomed in lieu of the standard 80-percent ferro customarily employed in normal times. Specifications for spiegeleisen likewise were lowered from 20 percent to 16 percent Mn, and the relative employment of spiegel instead of ferro increased materially.

In 1917 the Leadville mines were open and operating and could increase the output of manganese ore readily and promptly as needed. Today, the mines that were most productive of manganese are flooded, caved, and virtually abandoned. Production would be delayed by the vast amount of preparation required and would be expensive, particularly if the operation were sustained for only a year or two.

Beneficiation of Leadville Manganese Ores

Elimination of a large part of the iron as well as the acid-insoluble constituents is essential to any worthwhile improvement in the grade of Leadville manganiferous ores. The iron and manganese minerals appear not to be chemically combined and might be expected to be amenable to methods of mechanical concentration. However, tests by the Bureau of Mines have indicated such close interlocking of fine-grained manganese and iron minerals that there is no possibility of their physical separation. Otherwise the composition of the ore is such that magnetic separation following a reducig roast would have naturally suggested itself as a means of preparing a product high in manganese and low in iron that would be satisfactory for the manufacture of spiegeleisen or ferromanganese.

Samples of both oxidized material and manganosiderite sent to Bureau stations are being studied by the Metallurgical Division to discover an economically feasible method of beneficiating them. Results to date are negative but virtually eliminate the possibility of mechanical separation of the iron and manganese minerals.

Matte-smelting with copper sulfide to produce a copper-manganese matte that would be converted to metallic copper and manganese oxide slag is receiving further consideration. In tests made several years ago by Wartman, Potter, and Schmid at the Bureau of Mines Tucson station, loss of manganese in the slag owing to solubility of manganese sulfide in silicate slags was very high. This led to the conclusion that "The use of a copper-bearing matte as a collector of manganese would involve too great a waste of manganese to be a satisfactory method of concentration".[17] However, the current revival of interest in domestic manganese may well justify re-examination of this method, which offers intriguing possibilities where suitable ores are available locally.

The manganese doubtless can be leached from the Leadville ores and precipitated in the form of pure manganese metal by the electrolytic process recently developed by the Bureau of Mines. It is understood that electrolytic manganese now being produced at the Knoxville plant of the Electro Manganese Corporation is being sold for around 40 cents a pound; however, this is a small experimental plant operating on a hitherto untried process and costs are bound to be abnormally high. The processes employed are similar to those involved in the production of electrolytic zinc, and abundant raw material is available of higher grade than the average zinc ore. It seems a fair assumption that a large-scale commercial operation eventually could produce electrolytic manganese at a cost comparable to that of electrolytic zinc or electrolytic copper, in the range of 6 to 8 cents a pound, and that this metal could be delivered at steel centers for 10 cents or less. Normally, manganese in 80-percent ferro is delivered at steel plants at about 5 cents a pound. During the last war, 80-percent ferro rose to $290 per ton or 16 cents per pound of contained manganese.

Although it has not been tried and steel metallurgists are reluctant to concede its feasibility, the purpose and method of use of ferromanganese in steel manufacture suggest to the lay mind that the substitution of manganese metal might be technically possible and even advantageous. The manganese in ferro added to open-hearth steel in the furnace or the ladle deoxidizes iron oxide, prevents oxidation of iron and carbon, and removes sulfur and other impurities from the steel. These results are obtained because manganese has a greater affinity than iron for oxygen and sulfur. Varying percentages of carbon in the ferro are desired for making different grades of steel, but the iron in ferro appears to have no part in the steel-making process. It is present as an essential ingredient in the product of ferro manufacture in the blast furnace, where it reduces volatilization loss of manganese. Doubtless ferro of any desired composition could be made by the simple expedient of melting manganese metal and iron in suitable proportions and adding carbon to the melt.

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[17] Wartman, F. S., Potter, G. M., and Schmid, M. D., Progress Reports - Metallurgical Division. 18. Studies in the Metallurgy of Copper Distribution of Manganese Between Matte and Slag in the Smelting of Copper: Bureau of Mines Rept. of Investigations 3340, 1937, p. 9

Although the necessity may be remote, the technical feasibility of utilizing electrolytic manganese in this manner should be investigated, bearing in mind the possibility that the metal eventually may be produced from low-grade ores, of which there is an abundance in the United States, at a cost of 6 to 8 cents a pound and thus might provide a considerable supply in an emergency that would justify the relatively high cost.

From a purely technical standpoint, disregarding the cost factor, it appears that substitution of pure manganese metal for ferro in the open-hearth process of steel manufacture might disturb operating procedure less than the employment of ferro or spiegel of lower grade than that to which the furnace men are accustomed. There is little evidence that modification of furnace practices to meet exigencies of supply during the World War caused any serious dislocation of the steel industry.

Experimentation with Leadville ores by the Metallurgical Division of the Bureau of Mines is continuing.

Cost and Time Required to Prepare Mines for Production

Mines in the Carbonate Hill, Fryer Hill, and Downtown areas that have produced the bulk of the manganese ores were virtually abandoned about the end of 1930, when low metal prices and the high cost of pumping large volumes of water combined to make operations unprofitable. In the intervening years old workings in the heavy ground characteristic of the district have caved rather generally and are inaccessible. Measurements in the shafts have shown that the water has risen to within 161 feet of the surface at the Penrose, 236 feet at the Daly on Fryer Hill, and 466 feet at the Greenback and remains virtually stationary at those levels. The water level in the Downtown section appears to be controlled by elevation of the collar of the A. V. and other shafts in lower California Gulch, from which water is overflowing, and in the other areas by intervening underground barriers that divide them into separate hydrostatic basins. At the time these measurements were taken, water in the Penrose stood at 10,132 feet, in the Greenback at 10,165 feet, and in the Daly at 10,220 feet.

The lower limit of oxidation ranges in different sections from 100 to several hundred feet below the present ground-water level which, in turn, may be from zero to 450 feet or more below the surface of the ground.

Loughlin estimates the average depth of oxidation for the district as 525 feet below the ground surface, ranging from 75 to 940 feet and roughly conforming to the bedrock contour.[18] The ground-water level averages around 300 feet below the ground surface; hence, it may be assumed that half or more of the old carbonate stopes and remnants of oxide ore bodies are now under water and can be reached only by pumping or drainage. In the Downtown area where the glacial drift and lake beds reach a depth of more than 300 feet, virtually all productive horizons are under water. In the Fryer Hill area some of the oxide bodies are above the ground-water level, and experience in the Chrysolite group, from which 30,000 tons of 16- to 20-percent manganese ore was shipped from 1936 to 1939, shows that extensive bodies of ore can be reached with a moderate amount of pumping. In the Carbonate Hill area a large part of the oxide zone is above water, and in Iron Hill virtually all major productive horizons are drained by the Yak Tunnel. It is possible that some mines on the south slope of Rock Hill that have produced a good deal of manganese ore are drained down to approximately the Yak Tunnel level through a tunnel from Iowa Gulch.

(a) Disposal of water by pumping

During 1915 and 1916 the Downtown mines were unwatered through the Penrose shaft. Water was pumped at the rate of 2,000 to 2,700 gallons per minute for more than a year before the lower levels were drained and station pumps could be installed on the bottom level to handle the inflow. Equipment was reported to have cost about $65,000,[19] and the pumping operations probably cost well over $100,000. After the mines were drained the inflow was said to be about 1500 gallons per minute. On this basis it would cost around $200,000 to unwater the Downtown area and in the neighborhood of $60,000 a year to keep it drained.

The Leadville unit of the United States Smelting, Refining & Mining Co. unwatered East Fryer Hill mines in 1915 through the Harvard shaft. Pumping at the rate of about 1000 gallons per minute unwatering was completed in about a year. Thereafter, the inflow was found to be 500 to 600 gallons per minute. No data have been found to indicate how large an area was drained by this operation except that mines on Carbonate Hill were not affected to any extent. The cost, including equipment, of unwatering this area would be about $80,000 and pumping thereafter would cost close to $25,000 per year.

The Leadville Deep Mines Co., a consolidation of the interests of Western Mining Co., Empire Zinc Co., Iron-Silver Mining Co., Adams Mining Co. and others in the Carbonate Hill-Graham Park area, started pumping in the Greenback and Pyrenees shafts in late September 1923. Unwatering was completed approximately 665 days later, in July 1925. It was reported that 6,000,000,000 gallons were pumped during this period and that the inflow was found to be 1,400 gallons per minute.[20] If these figures are correct, unwatering must have cost $500,000 to $600,000 and pumping thereafter close to $60,000 a year.

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[18] Work cited in footnote 3, p. 248.

[19] Hoskin, A. J., Unwatering projects at Leadville: Eng. and Min. Jour., vol. 103, 1917, pp. 483-487.

[20] Henderson, Chas. W., Gold, Silver, Copper, Lead, and Zinc in Colorado: Bureau of Mines Mineral Resources of the United States, 1926, part I, p. 756.

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The foregoing data are based on popular reports in the technical press and statements in "Mineral Resources" and probably represent an approximation of the truth. At any rate they serve to provide a rough measure of the cost of unwatering the principal areas in which reserves of manganese might be found and the time required. These data are summarized below.

Area	Unwatering		Subsequent pumping	
	Time, Months	Cost	Inflow, g.p.m.	Annual Cost
Downtown...........	15-18	$200,000	1500	$60,000
Fryer Hill.........	12-15	80,000	600	25,000
Carbonate Hill) Graham Park)....	22-24	600,000	1400	60,000
Total.........		$880,000	3500	$145,000

Repair of underground workings and mining of ore would, of course, proceed simultaneously with the pumping, beginning above the ground-water level and following the receding water downward. All classes of ore would be mined if metal prices offered profitable markets and would contribute to offset the cost of pumping.

(b) Disposal of water by drainage tunnel

A deep-level drainage tunnel has been projected to tap the Downtown, Fryer Hill, Carbonate Hill, and Iron Hill areas at a depth approximately 860 feet below the Yak Tunnel and well below prospectively productive horizons, except in a few places where the dip brings productive formations to greater depths.

The portal of the tunnel would be near the mouth of Thompson Gulch at an elevation of 9,400 feet. It would be driven in a northeasterly direction, on a grade of 10 feet per mile, 27,350 feet to the Penrose shaft; then 4,000 feet to the Greenback shaft and 4,300 feet beyond to the Cord winze below the Yak Tunnel. A lateral 3,600 feet in length from the Penrose shaft would reach the Daly shaft on Fryer Hill.

Distances from the portal and the depth of the projected tunnel at various points on a grade of 10 feet per mile would be as follows:

Point	Distance from portal		Elevation				Tunnel depth	
	Feet	Miles	Surface	Water	Shaft bottom	Tunnel	Below surface	Below water
Portal....	0	0	9,400			9,400	0	0
Penrose shaft....	27,350	5.18	10,293	10,132	9,399	9,451.8	841	680
Greenback shaft....	31,350	5.94	10,631	10,165	9,274	9,459.4	1,172	706
Cord winze.	34,650	6.75	10,950	10,330	9,730	9,467.5	1,483	863
Daly shaft.	30,950	5.86	10,456	10,220	10,139	9,458.6	997	761

Although information regarding the depths of shafts is uncertain, these figures are believed to be approximately correct. The tunnel would cut the Penrose shaft about 50 feet above the bottom and the Greenback about 185 feet up the shaft. It would be around 260 feet below the Cord winze and 680 feet below the bottom of the Daly shaft.

With respect to the formations the tunnel would pass through, Loughlin reports as follows:[21]

> The driving of the tunnel will encounter no serious difficulties. The first three miles or more of the tunnel would be in unconsolidated material. The next two as far as the Penrose shaft in the Downtown area, would be mainly in limestone in which no noteworthy faults or other obstacles are anticipated. Beyond the Penrose shaft both the branch to Fryer Hill and that to Carbonate Hill would cross one major and several minor faults and pass into granite. The extension from Carbonate Hill to Iron Hill will be mostly in granite but for a considerable distance in quartzite and limestone. It will cross two other major fault zones which will increase the cost of driving and maintenance but will present no great physical difficulties, as tunnels and other workings have been successfully maintained in them for years.

Proponents of the tunnel estimate its cost at $60 a foot, which would total $2,295,000 for the 38,250 feet immediately projected. The probable cost is spoken of locally in round numbers as 2-1/2 million dollars. Two intermediate shafts are planned in the 5-mile section from the portal to Penrose shaft. No definite information is available regarding the projected shafts, but inspection of the approximate course of the tunnel on contour maps of the district suggests that one might be located in Iowa Gulch at an elevation around 9600 feet and the other in the vicinity of Georgia Gulch at an elevation of about 10,100 feet. One would then be about 200 feet deep and the other about 700. Both probably would be all or nearly all in gravel or "lake beds". However, many shafts have been put down through these beds in the Downtown area, apparently without too great difficulty.

If no unexpected obstacles are found, the tunnel might be completed to the Penrose shaft in 18 months, including the time required to assemble and install equipment. This estimate is based upon the supposition that with modern equipment an average of 500 feet advance per month per heading could be maintained. The portal heading should do better than that, but progress in the shaft headings would be influenced by the amount of water to be handled. Another 8 months would be required to reach the Greenback and Daly shafts and 8 or 9 months to drive from the Greenback to the Cord winze. After the Penrose shaft has been tapped, the flow of water would be so great, if the mines are to be drained quickly, that tunnel operations doubtless would have to be suspended for several months.

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[21] Work cited in footnote 16.

The tunnel project appears to be a long-time proposition that has no bearing on the possibility of supplying an early need for manganese ore.

(c) Tonnage and grade of ore that might be produced at various prices

Ore averaging about 17 percent manganese and 22 percent iron was shipped to the Colorado Fuel & Iron at Pueblo in 1936, 1937, and 1939 from the Chrysolite properties. Output was 50 tons a day at times and was limited by the requirements of the steel plant rather than the capacity of the mines. The price paid in 1939, f.o.b. mines, netted between $6 and $7 a ton. The reason given for closing the mine and pulling the pumps on April 1, 1940, was that the steel plant had cut receipts to 300 tons a month, which was not enough to pay for the operation.

It is believed that if there were an assured market for 100 tons a day of 16- to 20-percent ore at a price of 40 to 50 cents a unit, f.o.b. mines, that amount would be forthcoming within 2 or 3 months. It is doubtful whether much more than 3,000 tons a month could be produced consistently for any extended time unless the price and prospects for continued demand were sufficiently attractive to justify large-scale unwatering projects that would drain the Downtown, Fryer Hill, and Carbonate Hill mines and the expenditure of large sums in reopening old workings. The maximum output of 104,115 tons in 1917 doubtless would have been exceeded in 1918 if the war had continued and could have been maintained for several years. However, at that time the mines were open and operating, producing all classes of ore of which manganese was a minor part, both in tonnage and value, and consequently had to bear only a small proportion of the cost of pumping and maintaining mine workings. Today, the mines are flooded and caved, and the cost of reopening them would constitute an excessive charge against the ore that might be expected to be recovered. Hence, it is believed that under any condition of demand likely to arise, production would be limited to such ore as lies above the water or could be reached with a moderate amount of pumping. Such evidence as is available indicates that most of the ore thus recoverable would be in the range of 16 to 25 percent Mn. A good deal of 30- to 40-percent ore was shipped from 1917 to 1920 at delivered prices around $1 a unit that netted $20 to $30 a ton at the mines, but, for the most part, reserves of this grade are believed to be economically inaccessible at this time. Operators who engaged in this business for a number of years state that shipments could be resumed but that prices would have to be higher than prevailed during the World War.

The conclusion is inescapable that no price likely to be offered would raise production much above the 100 tons or so a day that might be expected at $8 to $10 per ton net. This tonnage would be adequate to supply the needs for ore of this grade of local blast furnaces running at full capacity.